

# Overview Electrical Characterization— Mechanical Stress Effects

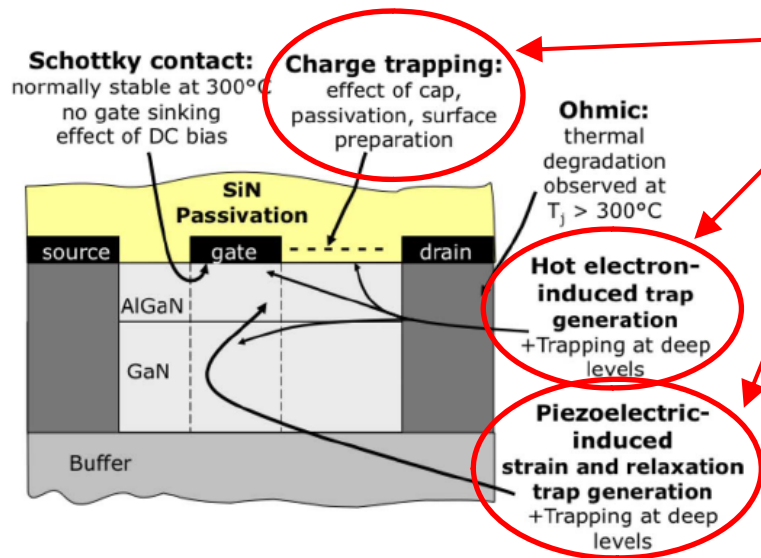
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Florida MURI Review

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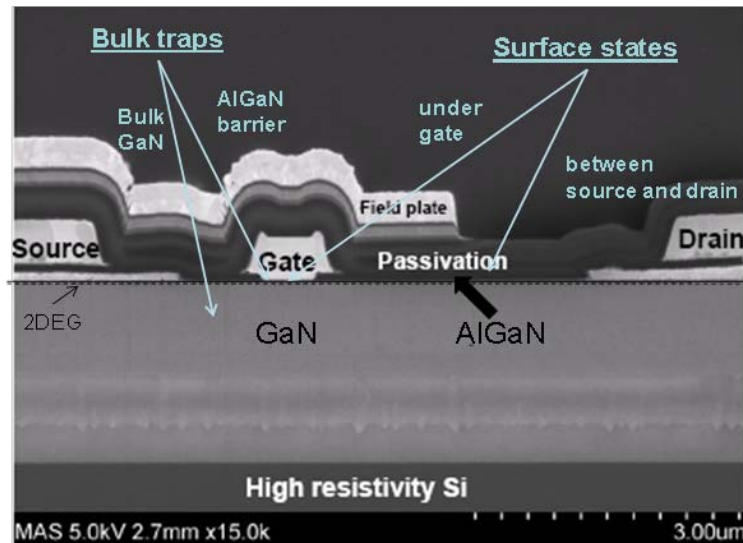
# Failure Mechanisms and Traps in GaN HEMTs



## Influenced by stress

- carrier mobility
- polarization and 2DEG
- Schottky barrier height
- bandgap
- trap energy levels
- generation of traps

G. Meneghesso, *et al.*, IEEE Trans on Device and Materials Reliability, Vol. 8, 2, 2008



## Traps in GaN HEMTs

### Cause

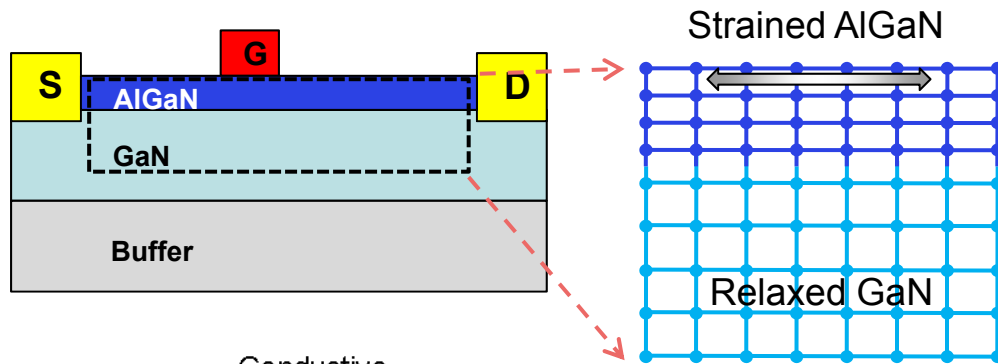
- growth as *fabricated* traps
- post growth process as *fabricated* traps
- hot-carrier injection *generated* traps
- inverse piezoelectric strain *generated* traps

### Effect

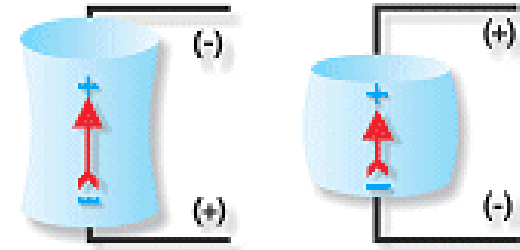
- current collapse
- gate-lag
- drain-lag
- $\Delta V_T$
- increased  $I_G$
- light sensitivity
- breakdown

# Stress in GaN HEMT Devices

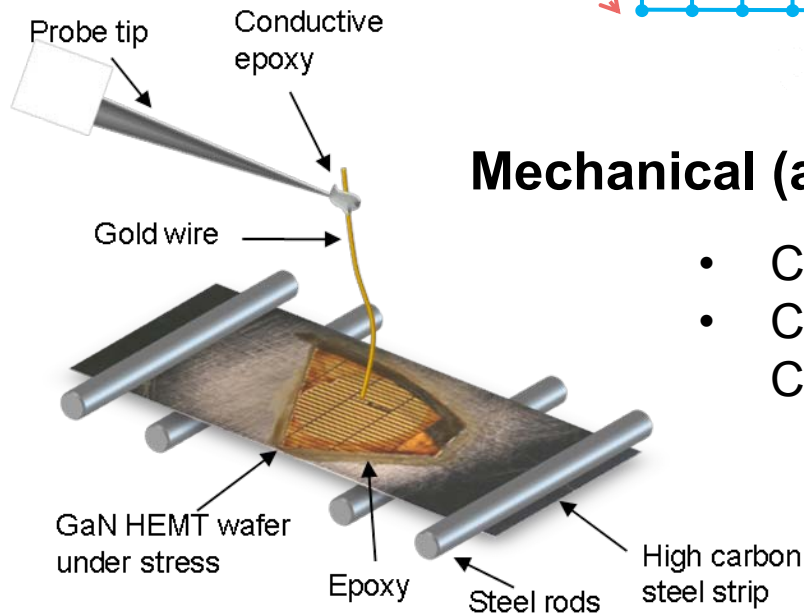
## Lattice mismatch (built-in) stress:



## Inverse piezoelectric (generated) stress:



## Mechanical (applied) Stress



- Cost effective method to study stress effects
- Can incrementally apply and release stress while Characterizing electrical response

# GaN HEMT Piezoresistance

Wide range of published gauge factors (  $GF = \frac{\Delta R}{R \cdot \varepsilon}$  )

Reference	GF	$\Delta R/R$	$\varepsilon$ (%)	$\sigma$ (MPa)	Method of Stressing
<b>Our work</b>	<b>-2.8</b>	<b>0.33%</b>	<b>0.114</b>	<b>360</b>	<b>4-point bending</b>
[1]	-4	0.14%	.03	95	3-point bending
[2]	-42	0.2%	.005	15	3-point bending
[3]	-75	3.5%	.04	126	3-point bending
[4]	-90	15%	0.167	525	Cantilever
[5]	-350	5%	.0143	45	Lever-Mass
[6]	-1,259	1.7%	$1.35 \times 10^{-4}$	0.42	Cantilever
[7]	-38,889	15%	$3.85 \times 10^{-4}$	1.2	Circular Membrane

[1] R. Gaska, et al, *APL*, vol. 72, pp. 64-66, (1998).

[2] M. Eickhoff, et al, *JAP*, vol. 90, 3383-3386, (2001).

[3] C. T. Chang, et al, *IEEE Electron Device Letters*, vol. 30, pp. 213-215 (2009).

[4] T. Zimmermann, et al, *IEE Electron Device Letters*, vol. 27, pp. 309-312, (2006).

[5] O. Yilmazoglu, K. et al, *EICE Trans Electron*, vol. E89-C, pp. 1037-1041, (2006).

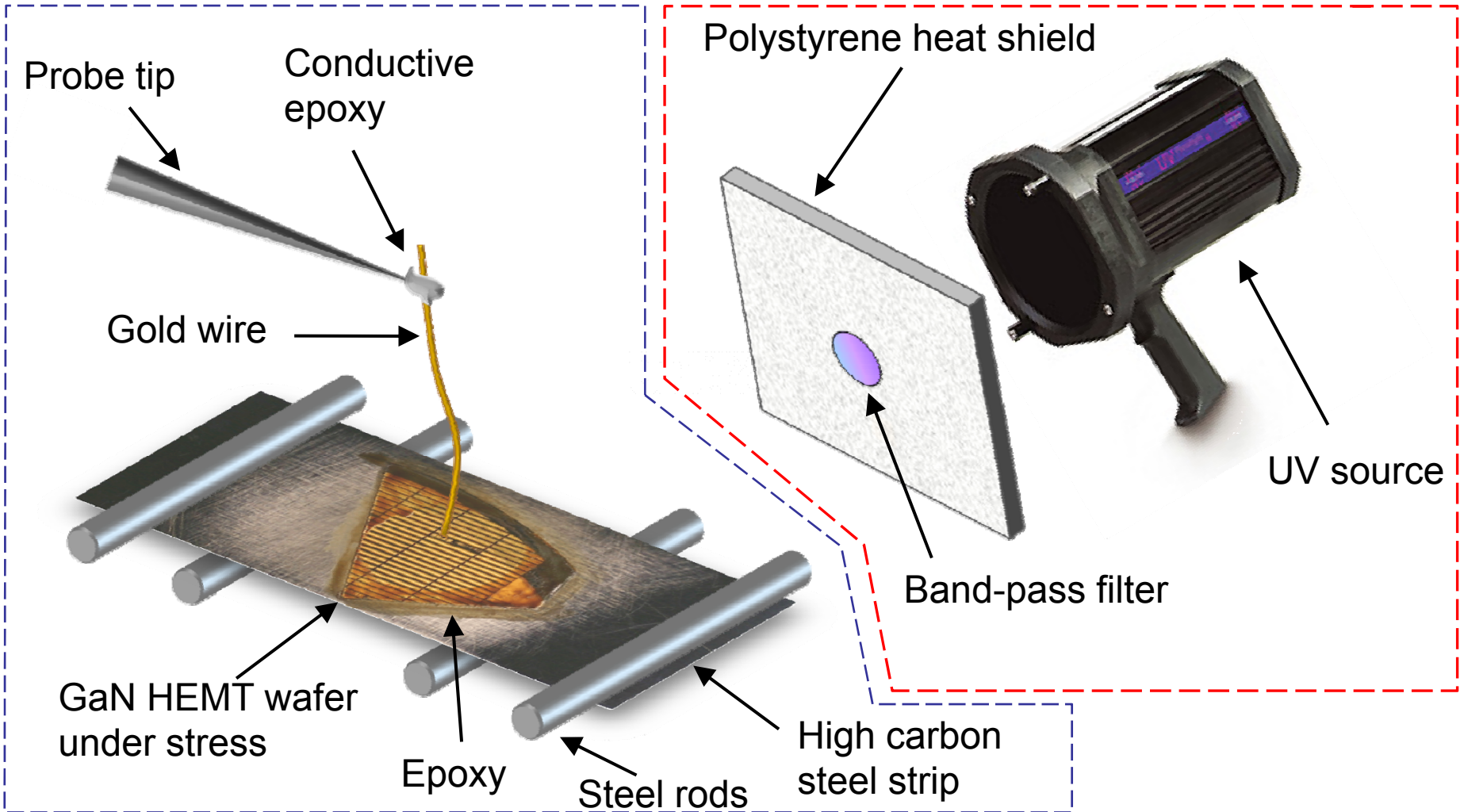
[6] B. S. Kang, et al, *APL*, vol. 83, 4845-4847, (2003).

[7] B. S. Kang, et al, *APL*, vol. 85, pp. 2962-2964, (2004).

# Experimental Setup – UV Illumination

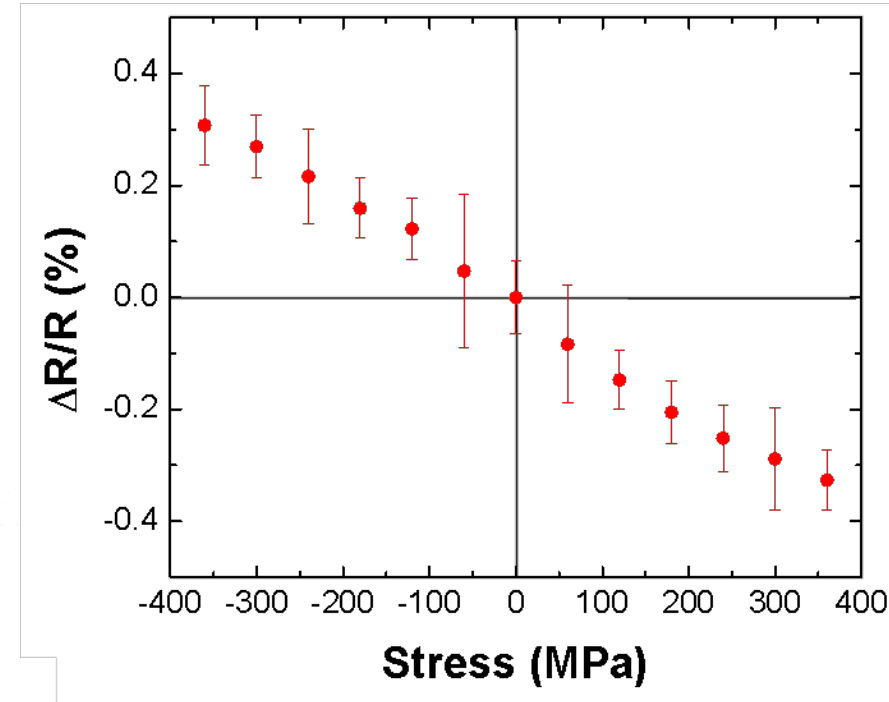
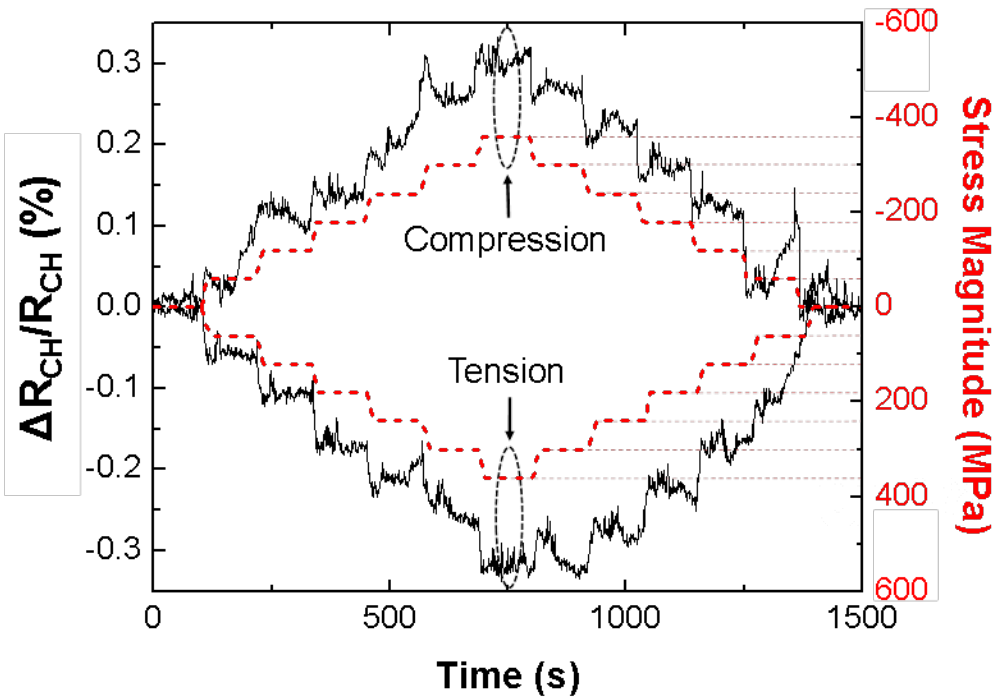
Electrical measurements under stress

Elimination of charge trapping effects





# GF Measurement Results

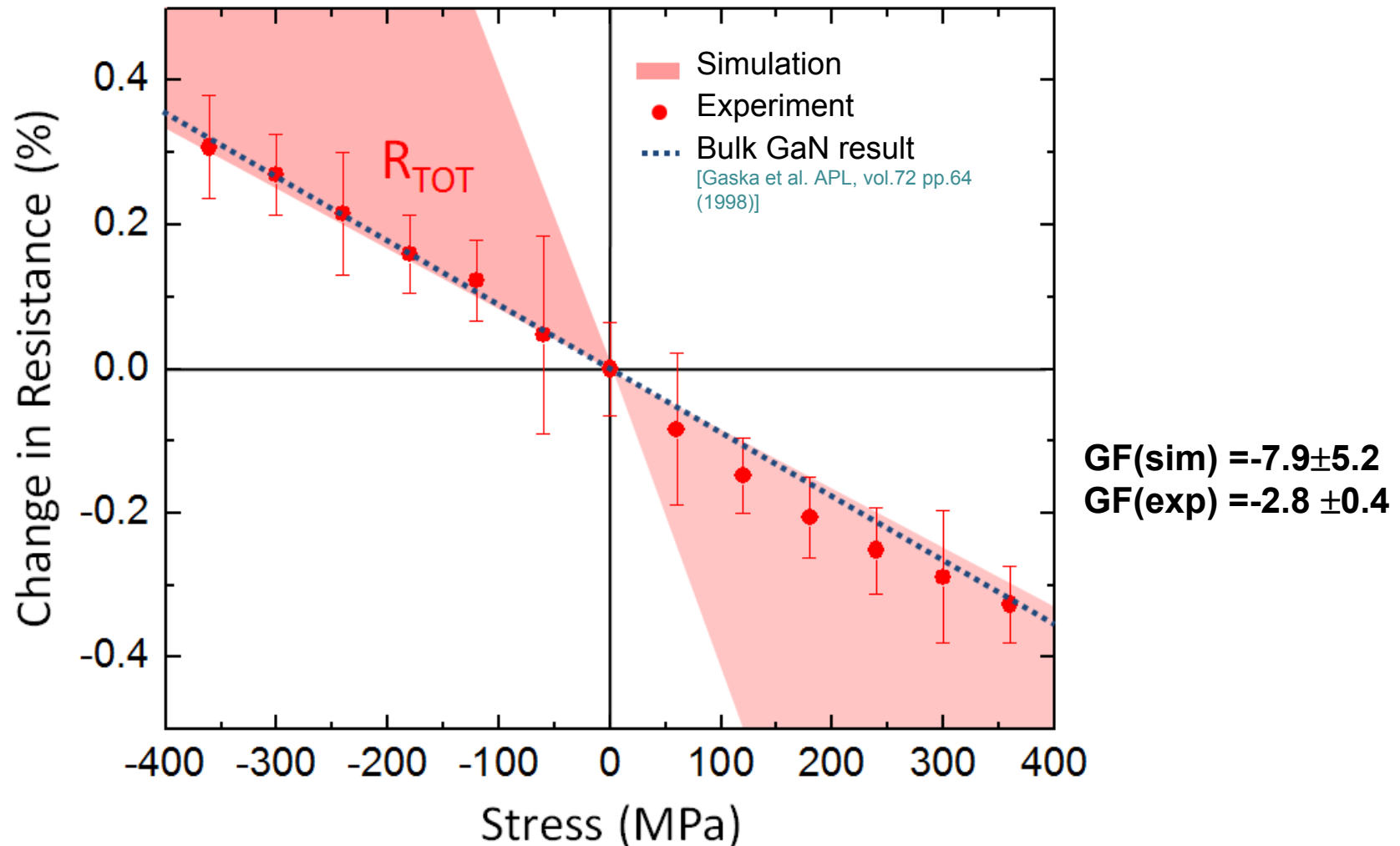


- Tensile stress decreases  $R_{CH}$
- Compressive stress increases  $R_{CH}$

	GaN HEMT
Gauge Factor	$-2.8 \pm 0.4$

A. D. Koehler et al., "Extraction of AlGaIn/GaN HEMT Gauge Factor in the Presence of Traps," IEEE EDL, Vol. 31, pp. 665-667, 2010.

# Stress-Varied Channel Resistance

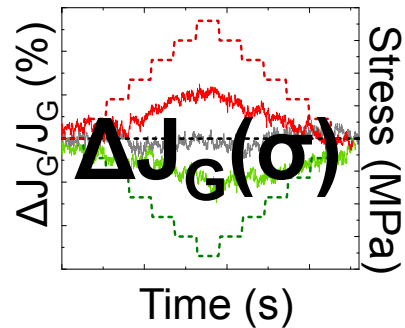
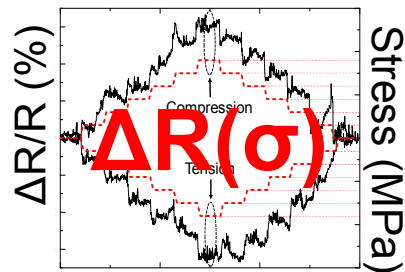


M. Chu et al., "Simulation of AlGaIn/GaN High-Electron-Mobility Transistor Gauge Factor Based on Two-dimensional Electron Gas Density and Electron Mobility," J. Appl. Phys., p. 104502, 2010.

# Mechanical Stress on GaN HEMT Reliability

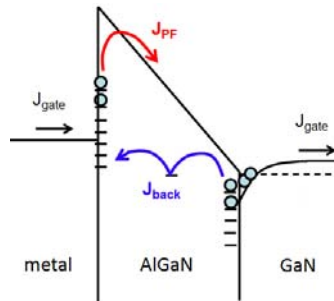
## FLOORS

### Stress Measurements

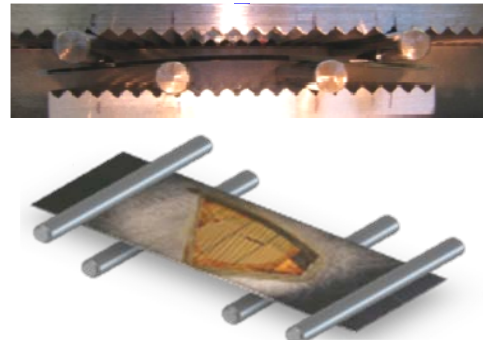


t=0, As Built

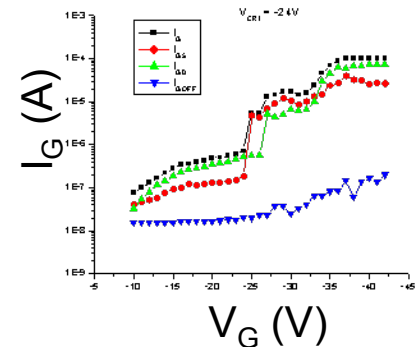
### Gate Leakage Modeling



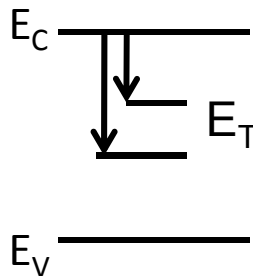
### Wafer Bending



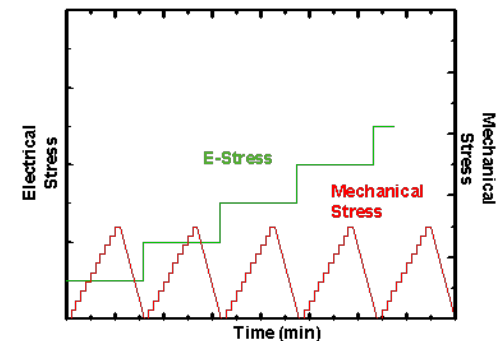
### Stress Measurements



### DFT Simulation



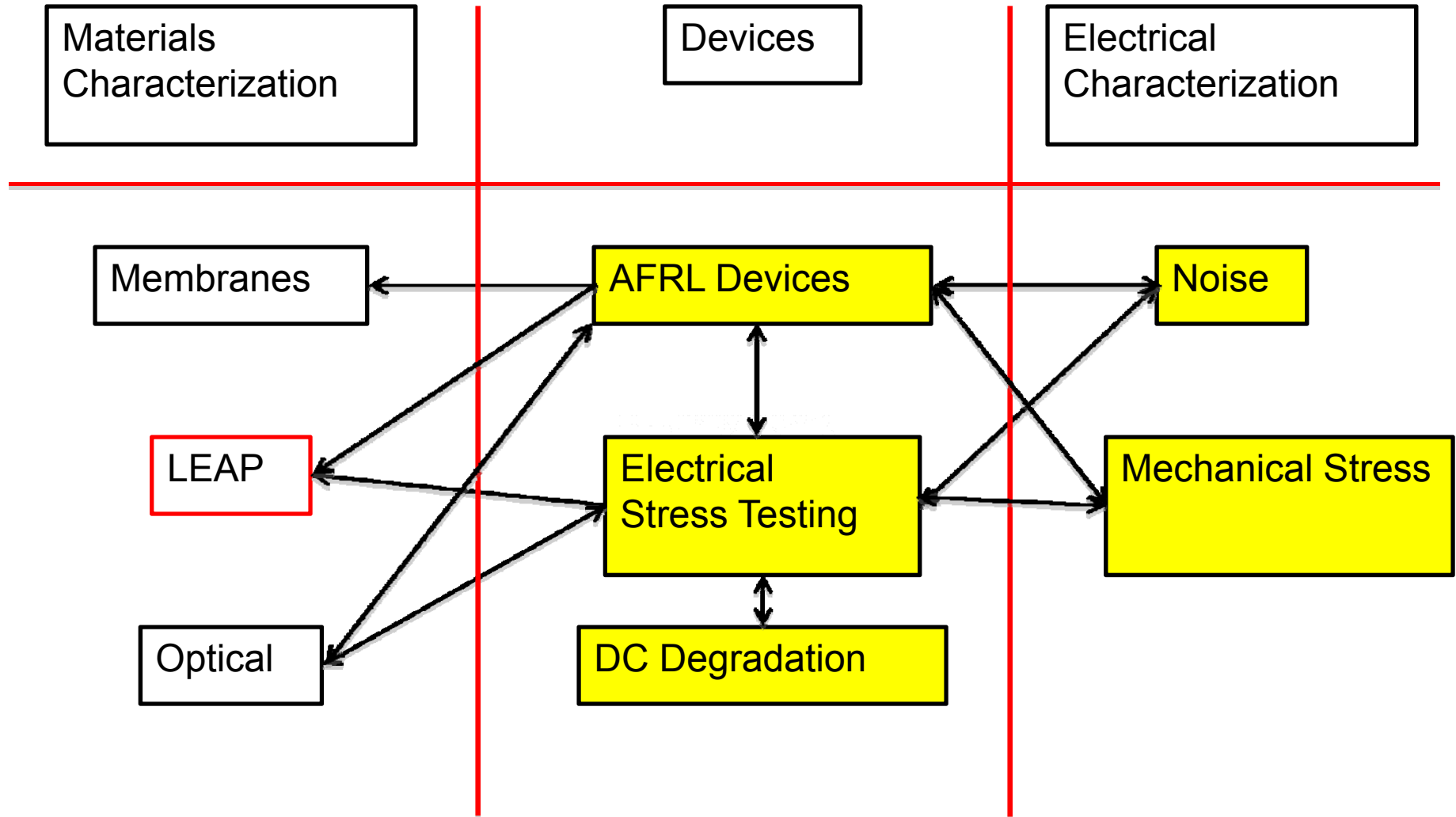
### LLO Devices



t>0, Degradation



# Device and Material Flow



# Theory Flow

